Title	Investigating physical properties of condensed matters using light and controlling their properties : Observation and control of new physical properties being opened up by terahertz-wave technology
Sub Title	
Author	田井中, 麻都佳(Tainaka, Madoka)
Publisher	Faculty of Science and Technology, Keio University
Publication year	2014
Jtitle	New Kyurizukai No.16 (2014. 7) ,p.2- 3
JaLC DOI	
Abstract	
Notes	The Research
Genre	Article
URL	https://koara.lib.keio.ac.jp/xoonips/modules/xoonips/detail.php?koara_id=KO50001003-00000016-0002

Associate Professor Shinichi Watanabe is featured in this issue, whose field of research focuses on observing and controlling physical properties by means of terahertz light.

Investigating physical properties of condensed matters using light and controlling their properties

Observation and control of new physical properties being opened up by terahertz-wave technology

For a long time, humankind has used light with different frequencies (wavenumbers) to observe objects and change physical properties of things to improve living by harnessing electrical energy converted from light energy. In this context, coming into focus of attention is "terahertz light" that has longer wavelengths than visible light. We asked Associate Professor Shinichi Watanabe, a research specialist in THz spectroscopy about the terahertz-wave technology forefront.

What is terahertz light?

Light is indispensable for examining physical properties of things and for transforming such properties. Research based on light has developed in tandem with the development of technology to the extent that it is now contributing even to elucidating the origin of the universe – one of the greatest mysteries for humankind. Of the various kinds of light as a tool, terahertz light ("tera" signifies 10 raised to the power of 12) strongly comes into the limelight. Focused on studies based on terahertz light, Dr. Watanabe explains its advantages as follows:

"Terahertz light has extremely long wavelength, its frequency being 1/100 to 1/1000 that of visible light. Since light having a high frequency (wavelength is short) like X-ray has greater energy, we can say that terahertz light is light with a low level of energy.

The fact that its energy is extremely lower than that of X-rays means that terahertz light has significantly less adverse impact on the human body. This is why expectations are high for terahertz light as "safe light."

You can also say that examining physical properties of things is investigating their energy structure. For example, when attempting to examine low-energy objects like a superconductor, use of terahertz light is the only way to see it directly. In other words, each type of light has its specialty fields of application."

Moreover, terahertz light is very useful for penetrating materials, such as clothing, plastic packages and paper that do not transmit visible light. As such, much is expected of terahertz light for application to virtually all industrial fields – security check, semiconductor product inspection, non-destructive testing (on buildings, etc.), medical care and pharmaceutical development, to name a few. The study of terahertz light had remained unexplored until recently partly because the light can be absorbed with water and partly because it had been difficult to generate this light efficiently.

Dr. Watanabe continues: "An intriguing aspect of terahertz light is that its slow vibration allows us to observe its waveform (flying through the air) as is. I'm interested in both seeing physical properties of things and manipulating them. So it's very exciting to be able to see firsthand what's going on the moment light strikes an object and how they interact with each other. Due to its extremely low frequency, terahertz light also has properties very similar to radio waves. This makes it possible to produce similar effects – effects that could be obtained when an electric or magnetic field is given – without attaching an electrode to the object concerned. This is truly intriguing."

By having both the radio wave-like property of transmitting a variety of substances together with the property of travelling straight like visible light, terahertz light covers a wide range of measurement objects. This is the greatest characteristic of terahertz light.

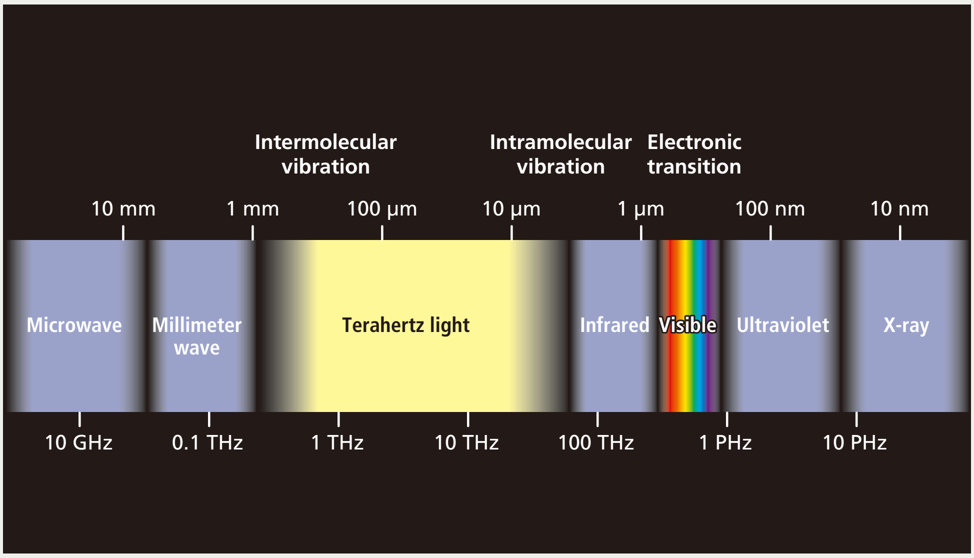


Fig. 1
What is terahertz light?
Its frequency centered around 10^{12} Hz, terahertz light has wavelengths 100 to 1,000 times longer than those of visible light and, as such, it is positioned at the border between radio waves and light waves. Having long wavelengths means its photon energy is low, which makes it possible for us to examine low-energy structures such as superconducting gap and intermolecular vibration.

Applying "terahertz time-domain spectroscopy"

The Watanabe lab currently employs a method known as the "terahertz time-domain spectroscopy." By mixing long-wavelength "terahertz light" and short-wavelength "near-infrared light pulse" in a transparent substance known as the "nonlinear optical crystal," this method allows us to identify terahertz light waveforms just like an oscilloscope (a waveform measuring device used to observe behavior of electrical signals).

He states: "In optical physics, we usually examine an object's energy structure by exposing an object to light and determining how much the intensity of its reflected light or transmitted light has decreased. In addition to determining changes in light intensity, "terahertz time-domain spectroscopy" also allows us to stagger the timing of near-infrared light pulse irradiation. Thus we can obtain double amount of information – changes in "amplitude" and "phase" of light waves."

Furthermore, by exercising additional ingenuity on this method, the Watanabe lab has succeeded in accurately measuring information relating to "polarization" in addition to amplitude and phase. By rotating at a high speed the semiconductor crystal for the terahertz pulse detection at a prescribed angular velocity, it has become possible to determine the magnitude and direction of terahertz light's electric field vector simultaneously. Thus, we are now able to accurately analyze the direction of reflected wave vector component.

Highly sophisticated calculation had been required to analyze signals resulting from semiconductor crystal rotation. But Mr. Naoya Yasumatsu, then a senior, completed the task after struggling with enormous amount of calculation involved.

"This method made it possible to accurately measure the direction of electric field vectors (at a given time) of terahertz-wave pulse light irradiated from two points of different height, leading us to perform highly accurate testing on the contour and surface roughness of metallic objects. As a result, we became able to distinguish unevenness down to the depth of one-thousandth of the wavelength. This achievement was publicized on the American Optical Society's 'Optics Letters' (online bulletin board version)."

Highly motivated, Dr. Watanabe said that he would like to expand application of this method even to the short-wave domains of infrared and visible light.

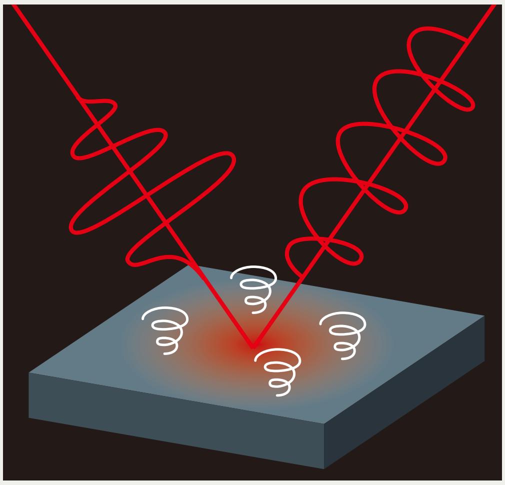
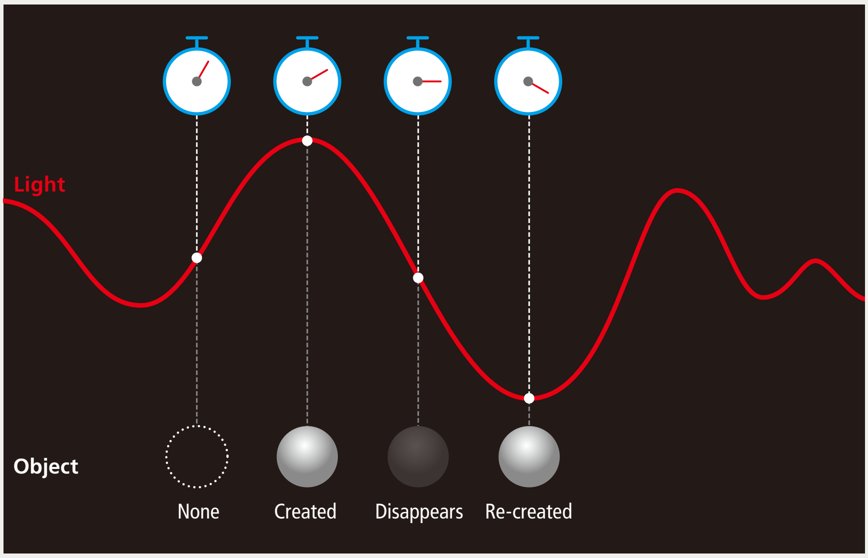


Fig. 2 Measurement of optical electric field vector waveforms

The Watanabe lab can display on monitor screen terahertz light's electric field vector waveforms, just in a manner that you observe electrical signals on an oscilloscope. Adding information on "polarization" to "amplitude" and "phase" enables us not only to observe an object's contour more in detail but also to examine what's going on inside it, such as electron spin behavior and vibration of crystal lattice.

Fig. 3 Looking into physical phenomena that occur within one cycle of light wave

When an object is irradiated with light, what interaction between light and the object occurs within an ultimately short time scale? This is an intriguing aspect of optical physics. When ultra-short pulse laser, which has an extremely short pulse time width, is combined with the terahertz light generation technology, irradiation of an object with terahertz light elucidates in detail about new physical phenomena: for example, the point of time at which the electrons in the object are created or disappear.



Transforming physical properties using terahertz light with large vibration amplitude

Dr. Watanabe's research themes also include attempts to transform physical properties of an object by irradiating it with terahertz light with large vibration amplitude.

He continues: "Intrinsically, energy comparable to that of visible light is required to excite (to transfer from the ground state to the high-energy state) electrons in a semiconductor. However, terahertz light can do the same if we make its vibration amplitude extremely larger. What's more, the great thing about terahertz light is that its waveforms are visible, which allows us to closely observe how the state of electrons changes and at which point of time.

Since the frequency of terahertz light is close to the vibration resonance frequency of lattices that constitute an object, it is relatively easy to cause resonance. By swaying the lattice greatly, we can also expect to cause a structural change to the object. We are thus able to change physical properties of objects as desired, which is expected to lead to diverse applications to new physical sciences. I'm highly motivated to establish innovative methods for controlling physical properties of things."

We would like to keep our eye on the development of terahertz light – a field of study with great potential.

(Reporter & text writer : Madoka Tainaka)